FIG. 1

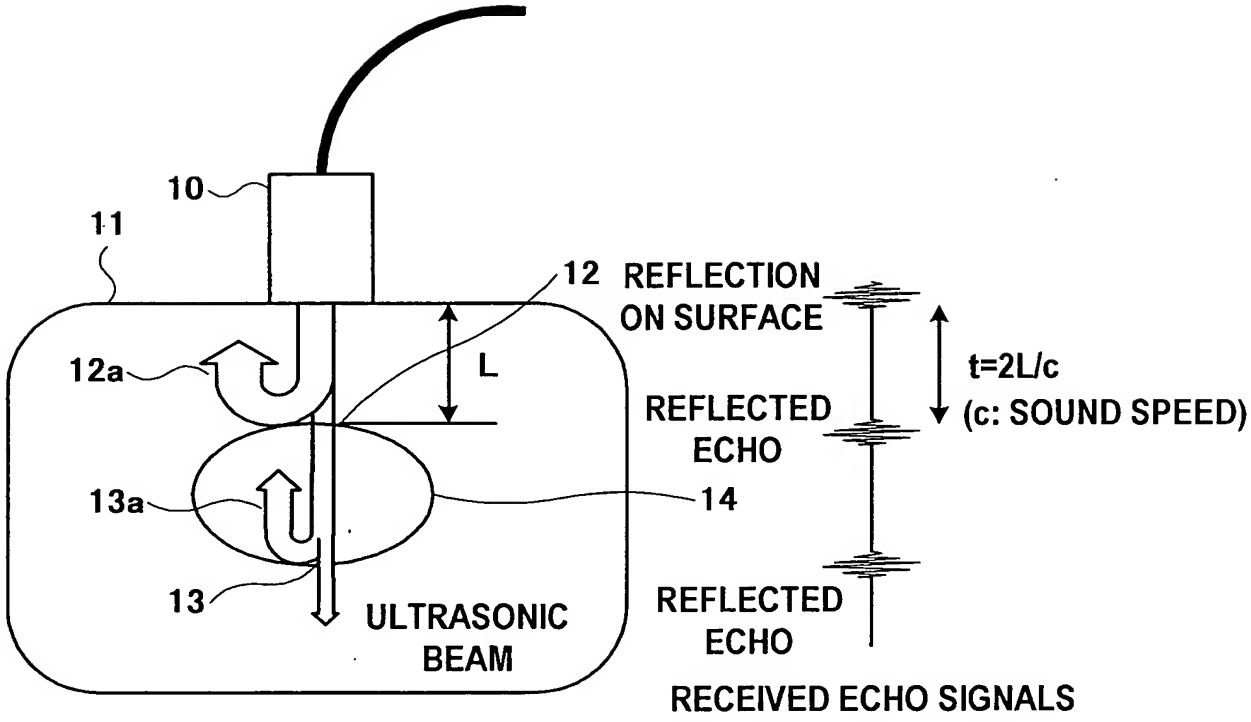

10
11
12
12a
L
13a
14
13
ULTRASONIC BEAM
REFLECTION ON SURFACE
REFLECTED ECHO
REFLECTED ECHO
t=2L/c
(c: SOUND SPEED)
RECEIVED ECHO SIGNALS

FIG. 2(A)

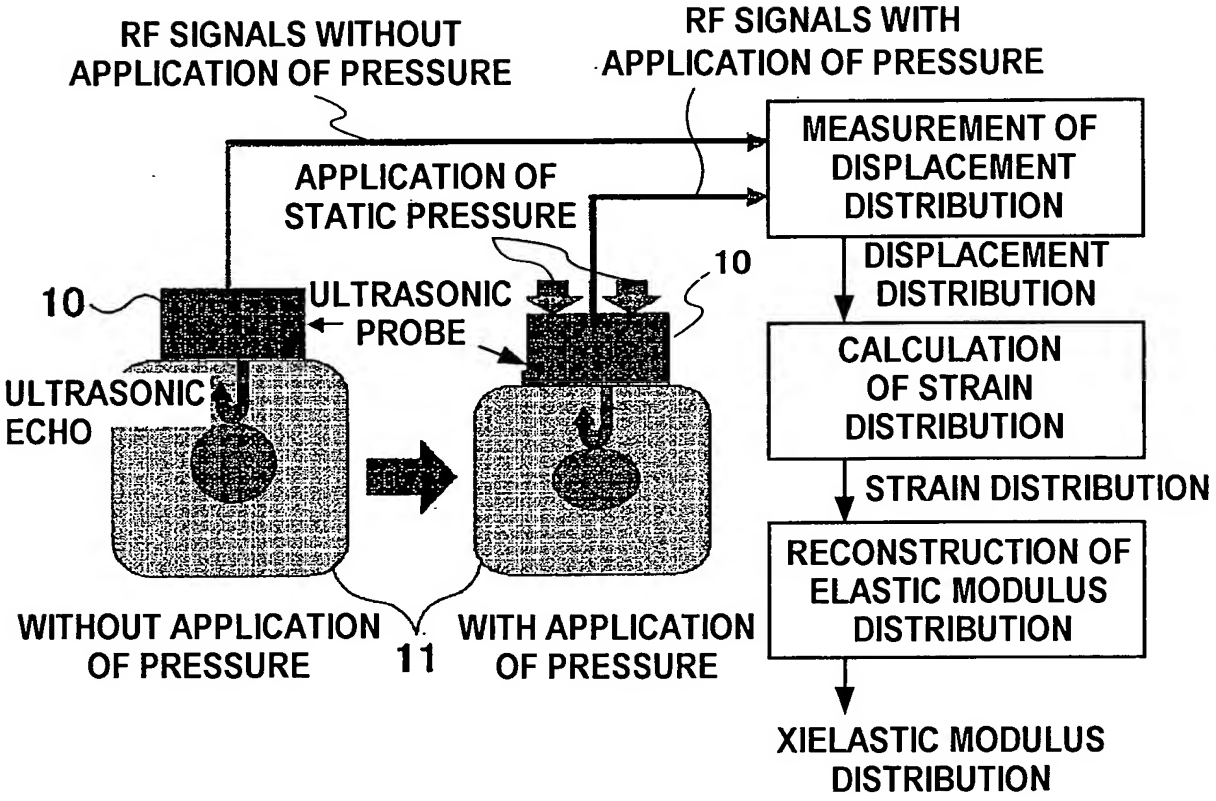

RF SIGNALS WITHOUT APPLICATION OF PRESSURE
RF SIGNALS WITH APPLICATION OF PRESSURE
MEASUREMENT OF DISPLACEMENT DISTRIBUTION
APPLICATION OF STATIC PRESSURE
DISPLACEMENT DISTRIBUTION
10
ULTRASONIC PROBE
10
ULTRASONIC ECHO
CALCULATION OF STRAIN DISTRIBUTION
STRAIN DISTRIBUTION
RECONSTRUCTION OF ELASTIC MODULUS DISTRIBUTION
WITHOUT APPLICATION OF PRESSURE
11
WITH APPLICATION OF PRESSURE
XIELASTIC MODULUS DISTRIBUTION

FIG. 2(B)

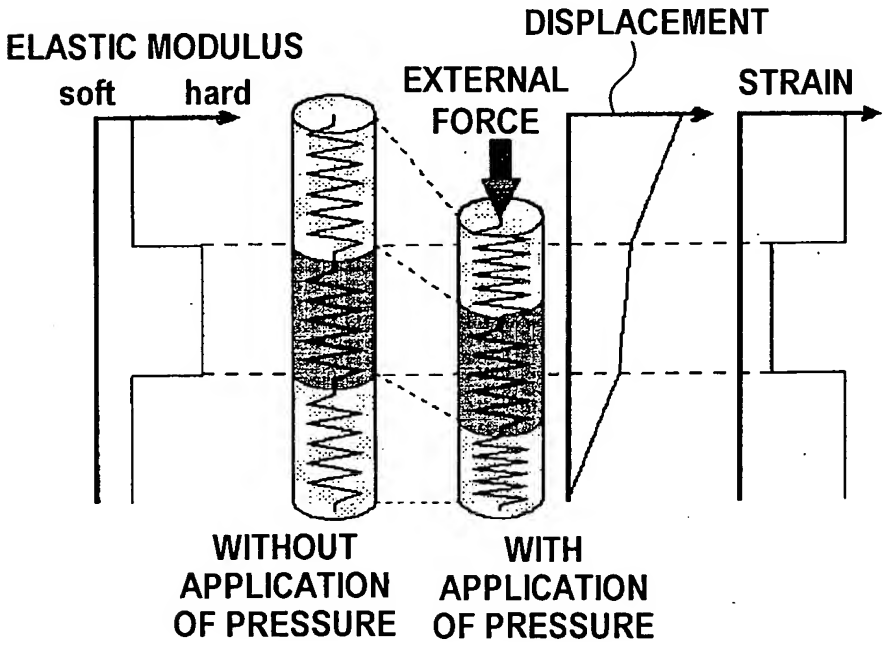

ELASTIC MODULUS
soft
hard
DISPLACEMENT
EXTERNAL FORCE
STRAIN
WITHOUT APPLICATION OF PRESSURE
WITH APPLICATION OF PRESSURE

FIG. 3

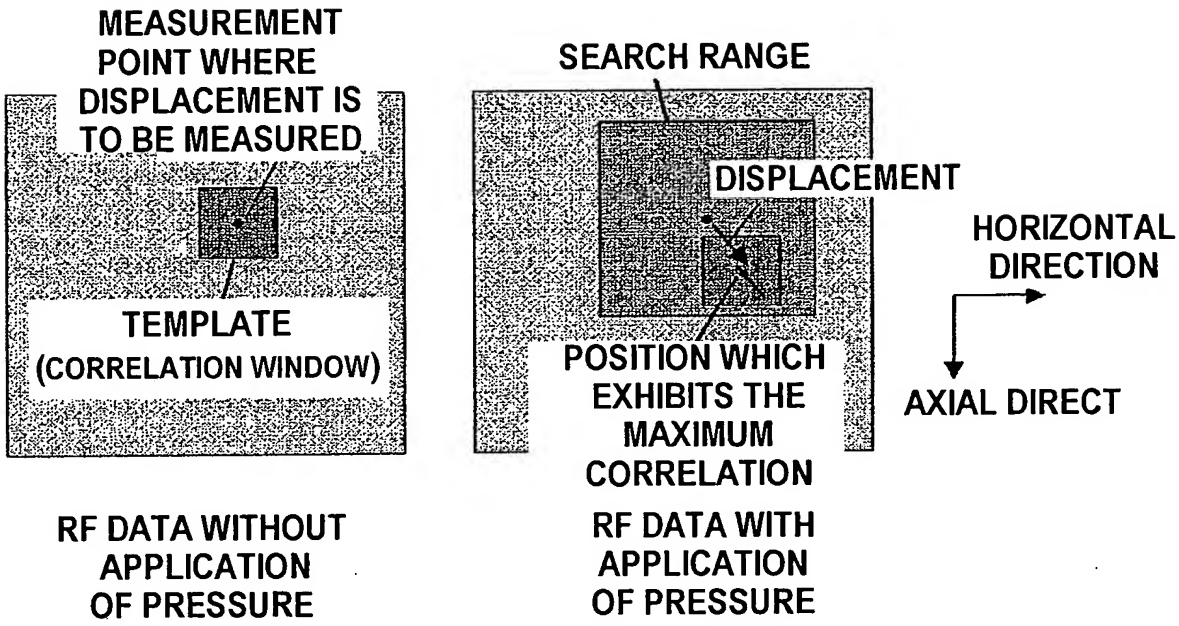

MEASUREMENT POINT WHERE DISPLACEMENT IS TO BE MEASURED
TEMPLATE (CORRELATION WINDOW)
RF DATA WITHOUT APPLICATION OF PRESSURE
SEARCH RANGE
DISPLACEMENT
POSITION WHICH EXHIBITS THE MAXIMUM CORRELATION
RF DATA WITH APPLICATION OF PRESSURE
HORIZONTAL DIRECTION
AXIAL DIRECT

FIG. 8

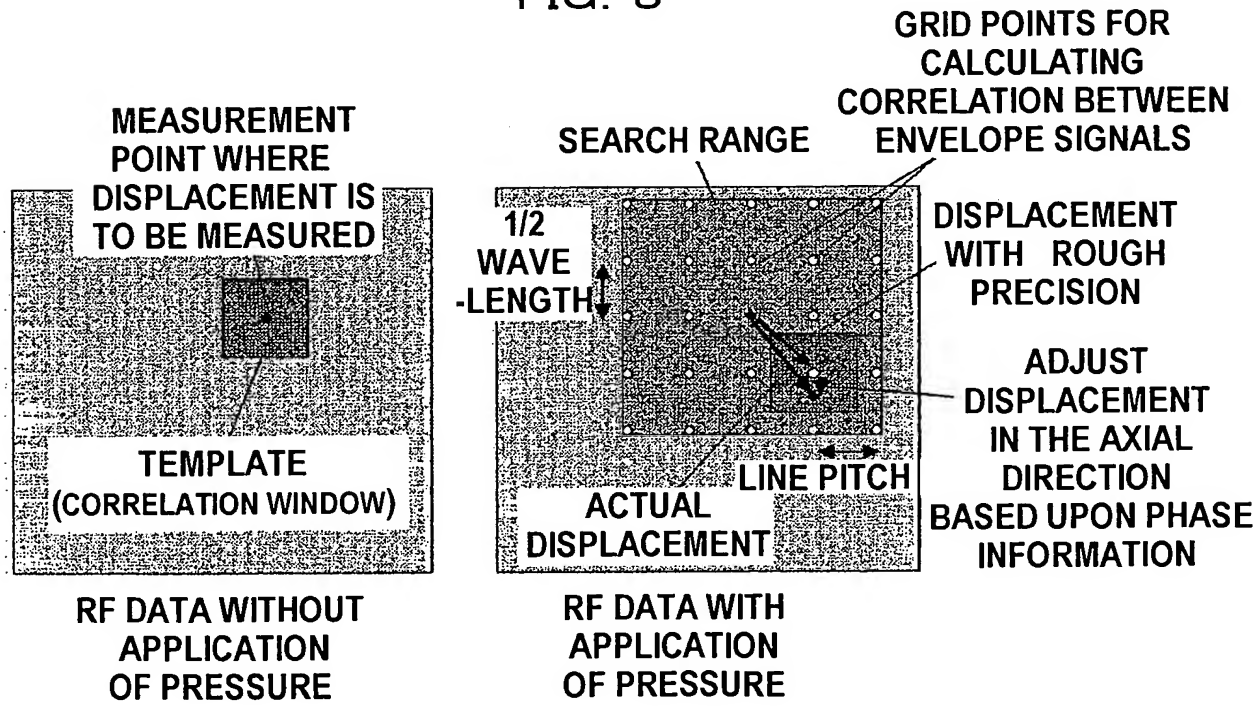

MEASUREMENT POINT WHERE DISPLACEMENT IS TO BE MEASURED
TEMPLATE (CORRELATION WINDOW)
RF DATA WITHOUT APPLICATION OF PRESSURE
SEARCH RANGE
GRID POINTS FOR CALCULATING CORRELATION BETWEEN ENVELOPE SIGNALS
1/2 WAVE -LENGTH
DISPLACEMENT WITH ROUGH PRECISION
ADJUST DISPLACEMENT IN THE AXIAL DIRECTION BASED UPON PHASE INFORMATION
LINE PITCH
ACTUAL DISPLACEMENT
RF DATA WITH APPLICATION OF PRESSURE

FIG. 4

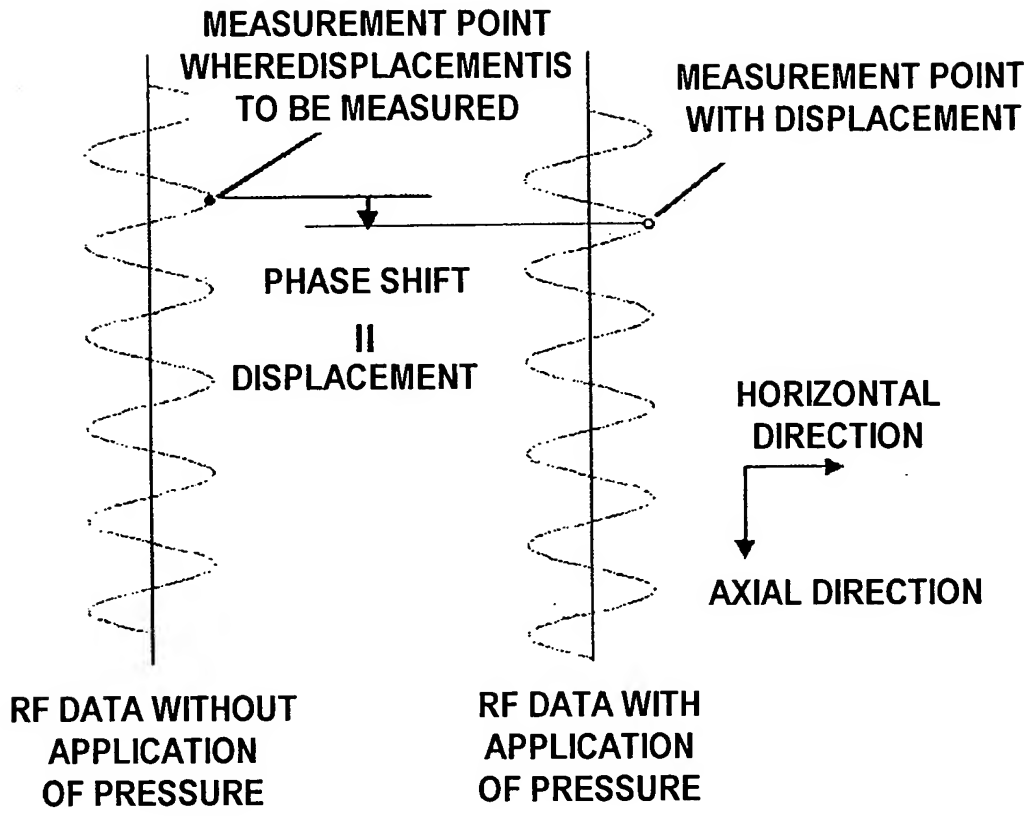

MEASUREMENT POINT WHEREDISPLACEMENTIS TO BE MEASURED
MEASUREMENT POINT WITH DISPLACEMENT
PHASE SHIFT
II
DISPLACEMENT
HORIZONTAL DIRECTION
AXIAL DIRECTION
RF DATA WITHOUT APPLICATION OF PRESSURE
RF DATA WITH APPLICATION OF PRESSURE

FIG. 5

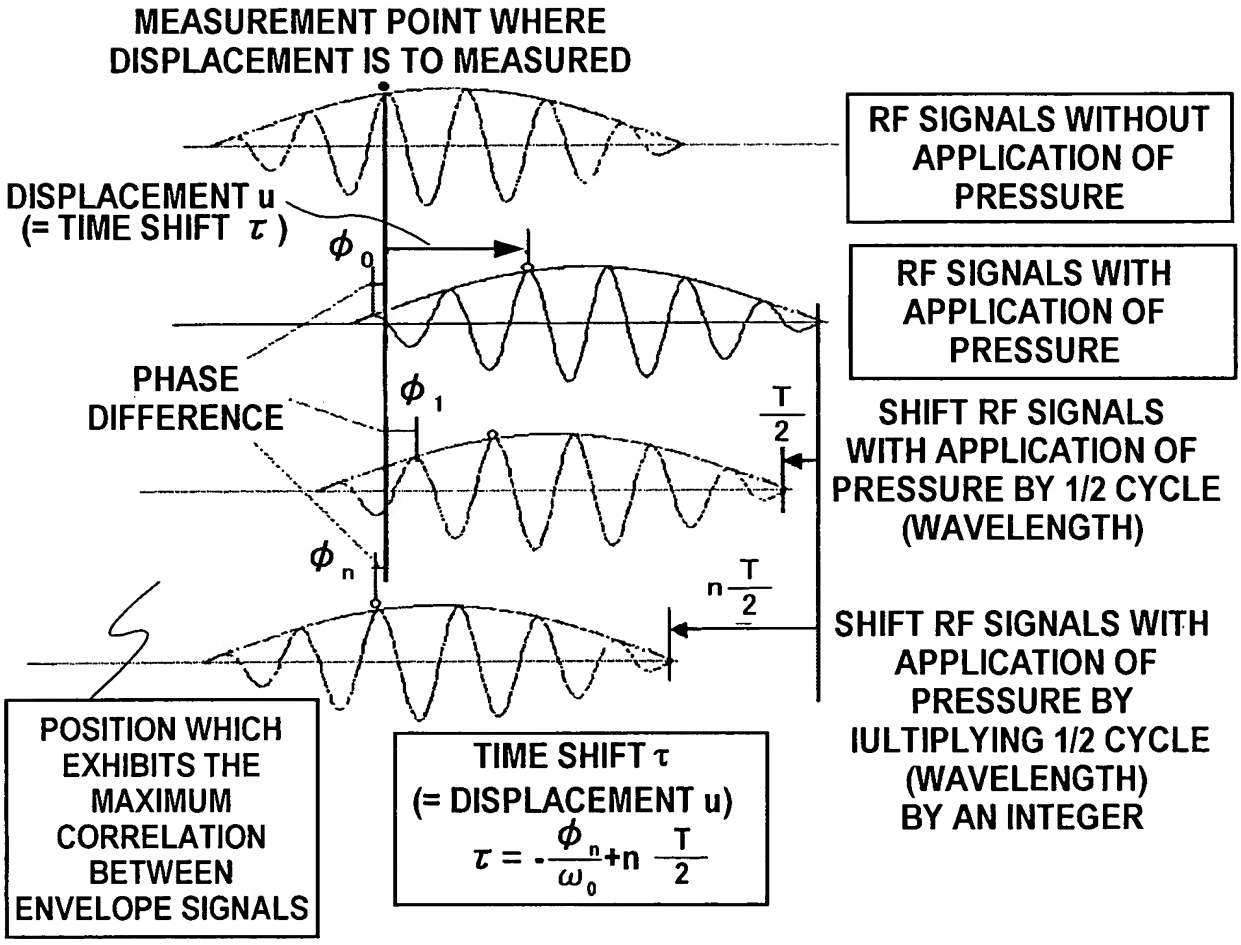

MEASUREMENT POINT WHERE DISPLACEMENT IS TO MEASURED
RF SIGNALS WITHOUT APPLICATION OF PRESSURE
DISPLACEMENT u (= TIME SHIFT τ)
φ0
RF SIGNALS WITH APPLICATION OF PRESSURE
PHASE DIFFERENCE
φ1
T/2
SHIFT RF SIGNALS WITH APPLICATION OF PRESSURE BY 1/2 CYCLE (WAVELENGTH)
φn
n T/2
SHIFT RF SIGNALS WITH APPLICATION OF PRESSURE BY IULTIPLYING 1/2 CYCLE (WAVELENGTH) BY AN INTEGER
POSITION WHICH EXHIBITS THE MAXIMUM CORRELATION BETWEEN ENVELOPE SIGNALS
TIME SHIFT τ
(= DISPLACEMENT u)
τ = -φn/ω0 + n T/2

FIG. 6

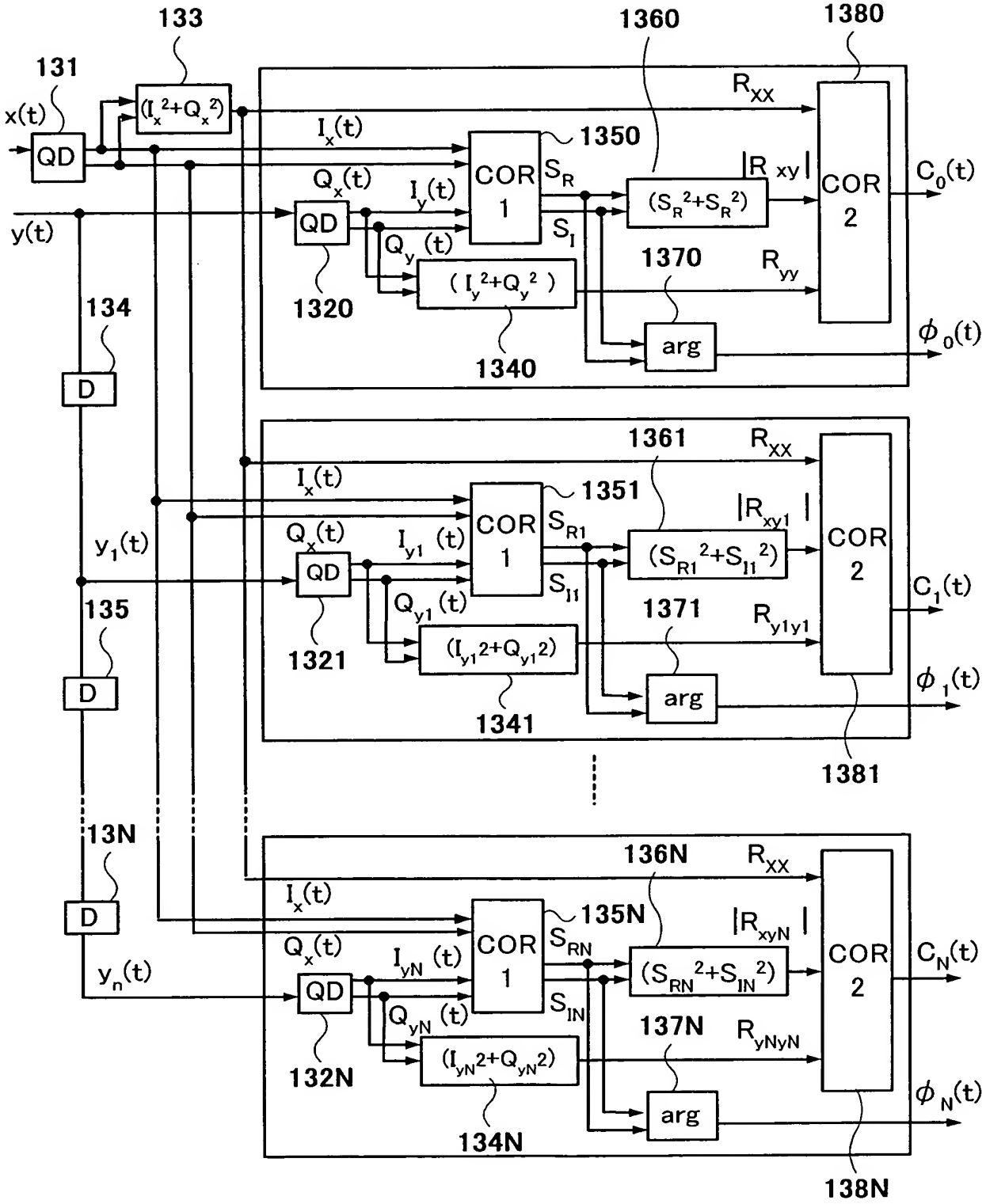

133
1360
1380
131
x(t)
QD
$(I_x^2+Q_x^2)$
R_{XX}
$I_x(t)$
1350
COR 1
S_R
$|R_{xy}|$
$C_0(t)$
COR 2
$Q_x(t)$
$I_y(t)$
$(S_R^2+S_R^2)$
y(t)
QD
S_I
$Q_y(t)$
1370
R_{yy}
$(I_y^2+Q_y^2)$
1320
134
arg
$\phi_0(t)$
1340
D
1361
R_{XX}
$I_x(t)$
1351
$|R_{xy1}|$
$y_1(t)$
$Q_x(t)$
$I_{y1}(t)$
COR 1
S_{R1}
$(S_{R1}^2+S_{I1}^2)$
COR 2
$C_1(t)$
QD
S_{I1}
135
$Q_{y1}(t)$
1371
R_{y1y1}
$(I_{y1}2+Q_{y1}2)$
1321
arg
$\phi_1(t)$
1341
D
1381
13N
136N
R_{XX}
$I_x(t)$
135N
$|R_{xyN}|$
$Q_x(t)$
$I_{yN}(t)$
COR 1
S_{RN}
$(S_{RN}^2+S_{IN}^2)$
COR 2
$C_N(t)$
$y_n(t)$
QD
S_{IN}
$Q_{yN}(t)$
137N
R_{yNyN}
$(I_{yN}2+Q_{yN}2)$
132N
arg
$\phi_N(t)$
134N
D
138N

FIG. 7

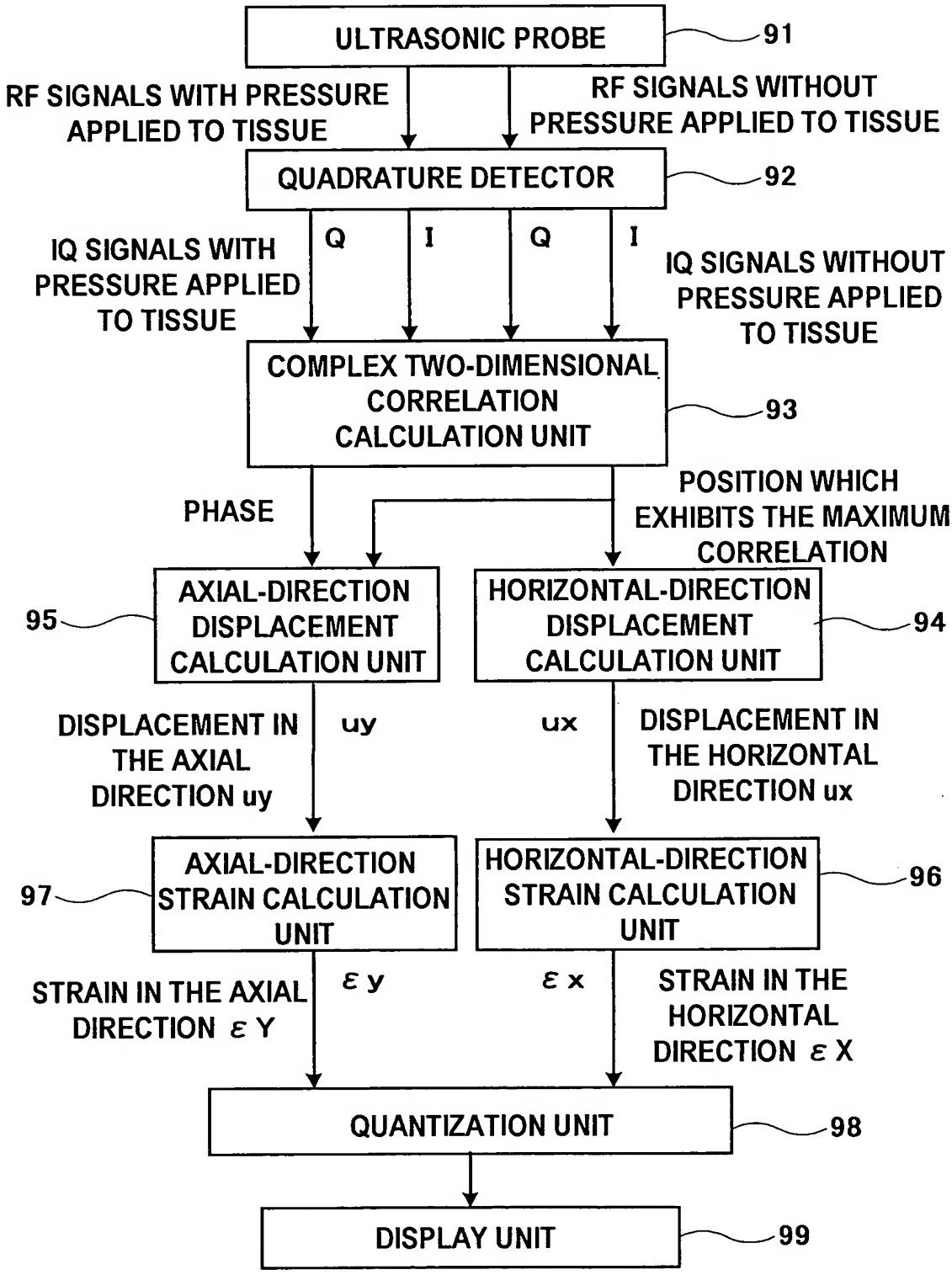

ULTRASONIC PROBE
91
RF SIGNALS WITH PRESSURE APPLIED TO TISSUE
RF SIGNALS WITHOUT PRESSURE APPLIED TO TISSUE
QUADRATURE DETECTOR
92
IQ SIGNALS WITH PRESSURE APPLIED TO TISSUE
Q
I
Q
I
IQ SIGNALS WITHOUT PRESSURE APPLIED TO TISSUE
COMPLEX TWO-DIMENSIONAL CORRELATION CALCULATION UNIT
93
PHASE
POSITION WHICH EXHIBITS THE MAXIMUM CORRELATION
95
AXIAL-DIRECTION DISPLACEMENT CALCULATION UNIT
HORIZONTAL-DIRECTION DISPLACEMENT CALCULATION UNIT
94
DISPLACEMENT IN THE AXIAL DIRECTION uy
uy
ux
DISPLACEMENT IN THE HORIZONTAL DIRECTION ux
97
AXIAL-DIRECTION STRAIN CALCULATION UNIT
HORIZONTAL-DIRECTION STRAIN CALCULATION UNIT
96
STRAIN IN THE AXIAL DIRECTION ε Y
ε y
ε x
STRAIN IN THE HORIZONTAL DIRECTION ε X
QUANTIZATION UNIT
98
DISPLAY UNIT
99

FIG. 9

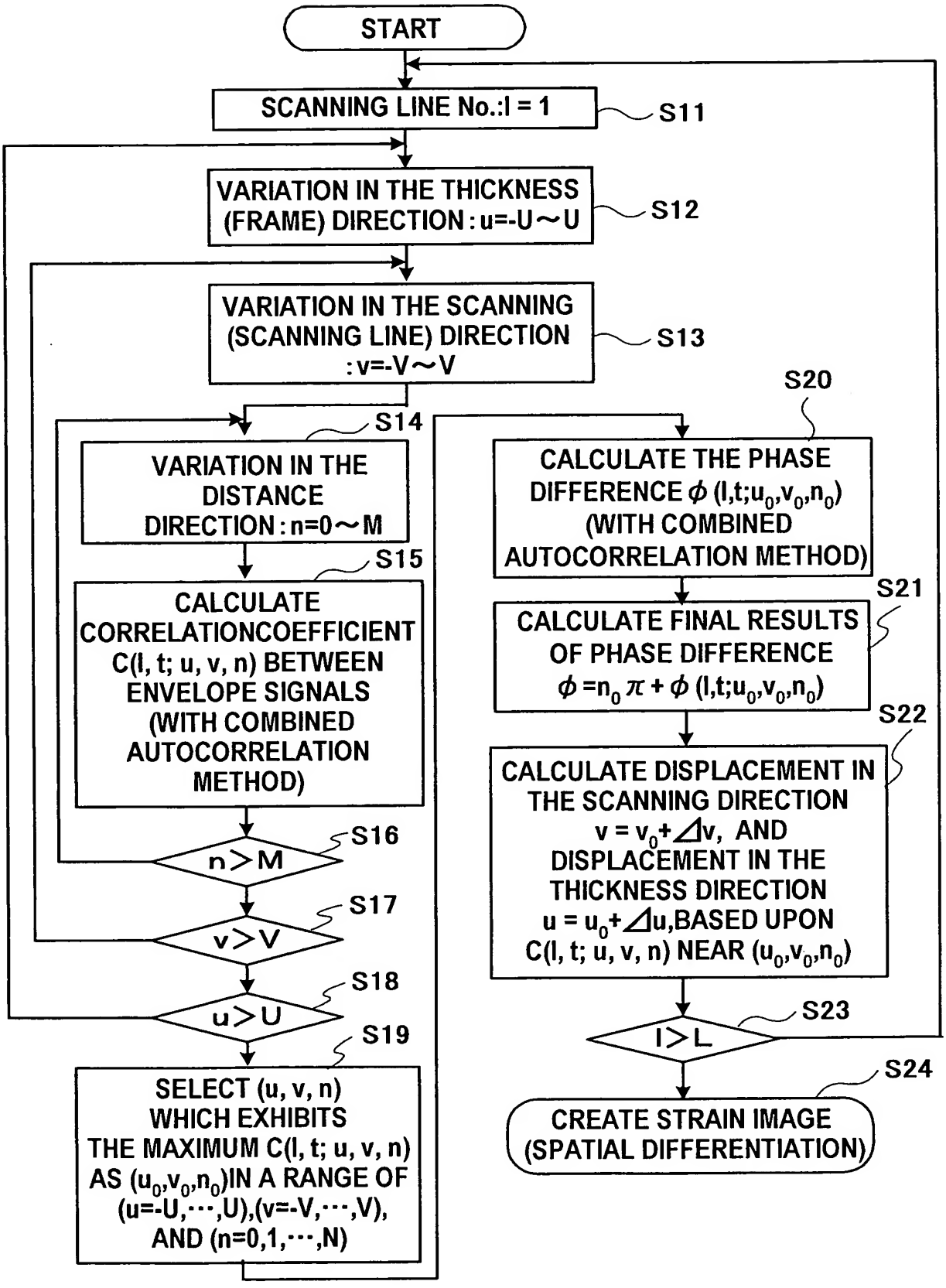

START
SCANNING LINE No.:l = 1
S11
VARIATION IN THE THICKNESS (FRAME) DIRECTION : u=-U～U
S12
VARIATION IN THE SCANNING (SCANNING LINE) DIRECTION :v=-V～V
S13
S14
VARIATION IN THE DISTANCE DIRECTION : n=0～M
S15
CALCULATE CORRELATIONCOEFFICIENT C(l, t; u, v, n) BETWEEN ENVELOPE SIGNALS (WITH COMBINED AUTOCORRELATION METHOD)
S16
n>M
S17
v>V
S18
u>U
S19
SELECT (u, v, n) WHICH EXHIBITS THE MAXIMUM C(l, t; u, v, n) AS (u0,v0,n0)IN A RANGE OF (u=-U,⋯,U),(v=-V,⋯,V), AND (n=0,1,⋯,N)
S20
CALCULATE THE PHASE DIFFERENCE φ (l,t;u0,v0,n0) (WITH COMBINED AUTOCORRELATION METHOD)
S21
CALCULATE FINAL RESULTS OF PHASE DIFFERENCE φ =n0 π + φ (l,t;u0,v0,n0)
S22
CALCULATE DISPLACEMENT IN THE SCANNING DIRECTION v = v0+Δv, AND DISPLACEMENT IN THE THICKNESS DIRECTION u = u0+Δu,BASED UPON C(l, t; u, v, n) NEAR (u0,v0,n0)
S23
l>L
S24
CREATE STRAIN IMAGE (SPATIAL DIFFERENTIATION)

FIG. 10

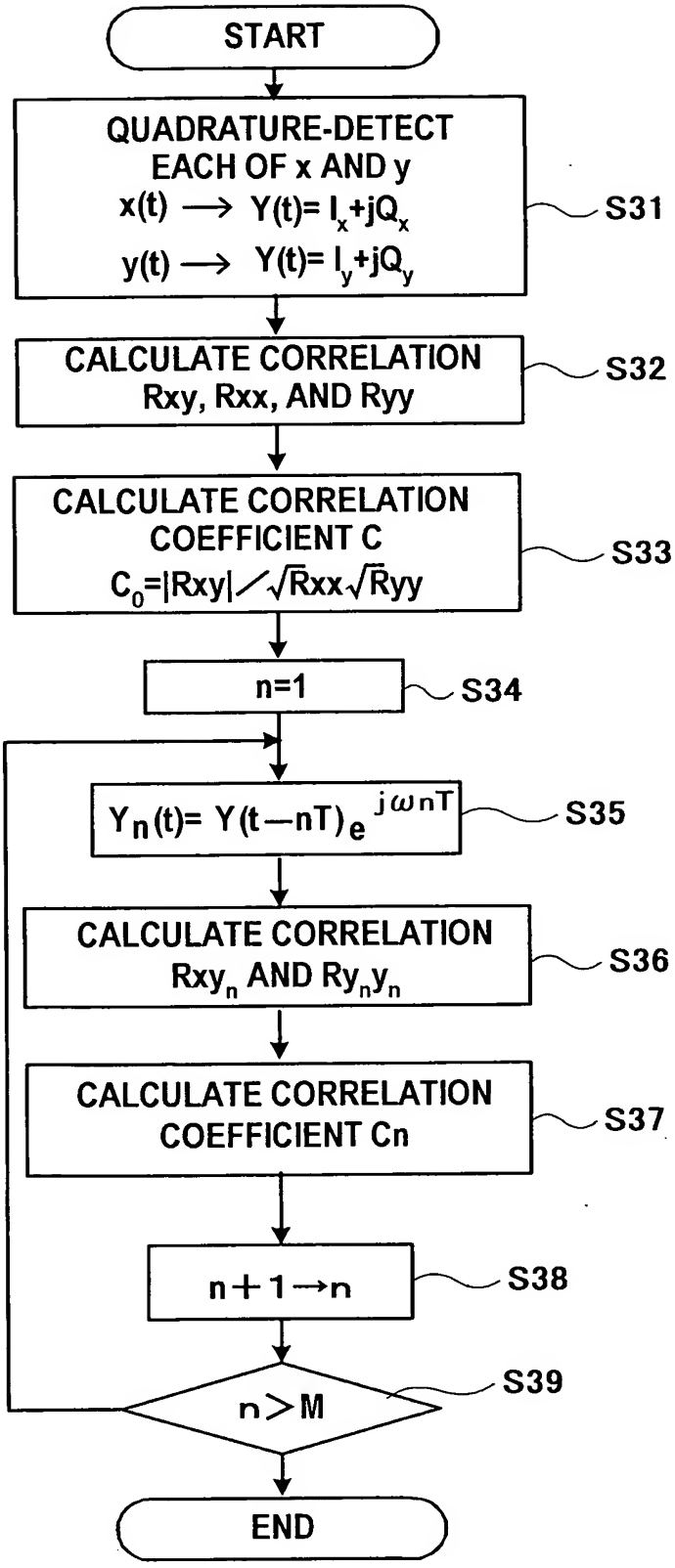

START
QUADRATURE-DETECT EACH OF x AND y
x(t) ⟶ Y(t)= I_x+jQ_x
y(t) ⟶ Y(t)= I_y+jQ_y
S31
CALCULATE CORRELATION Rxy, Rxx, AND Ryy
S32
CALCULATE CORRELATION COEFFICIENT C
C_0=|Rxy|/√Rxx√Ryy
S33
n=1
S34
$Y_n(t)= Y(t-nT)e^{j\omega nT}$
S35
CALCULATE CORRELATION Rxy_n AND Ry_ny_n
S36
CALCULATE CORRELATION COEFFICIENT Cn
S37
n+1→n
S38
n>M
S39
END

FIG. 11

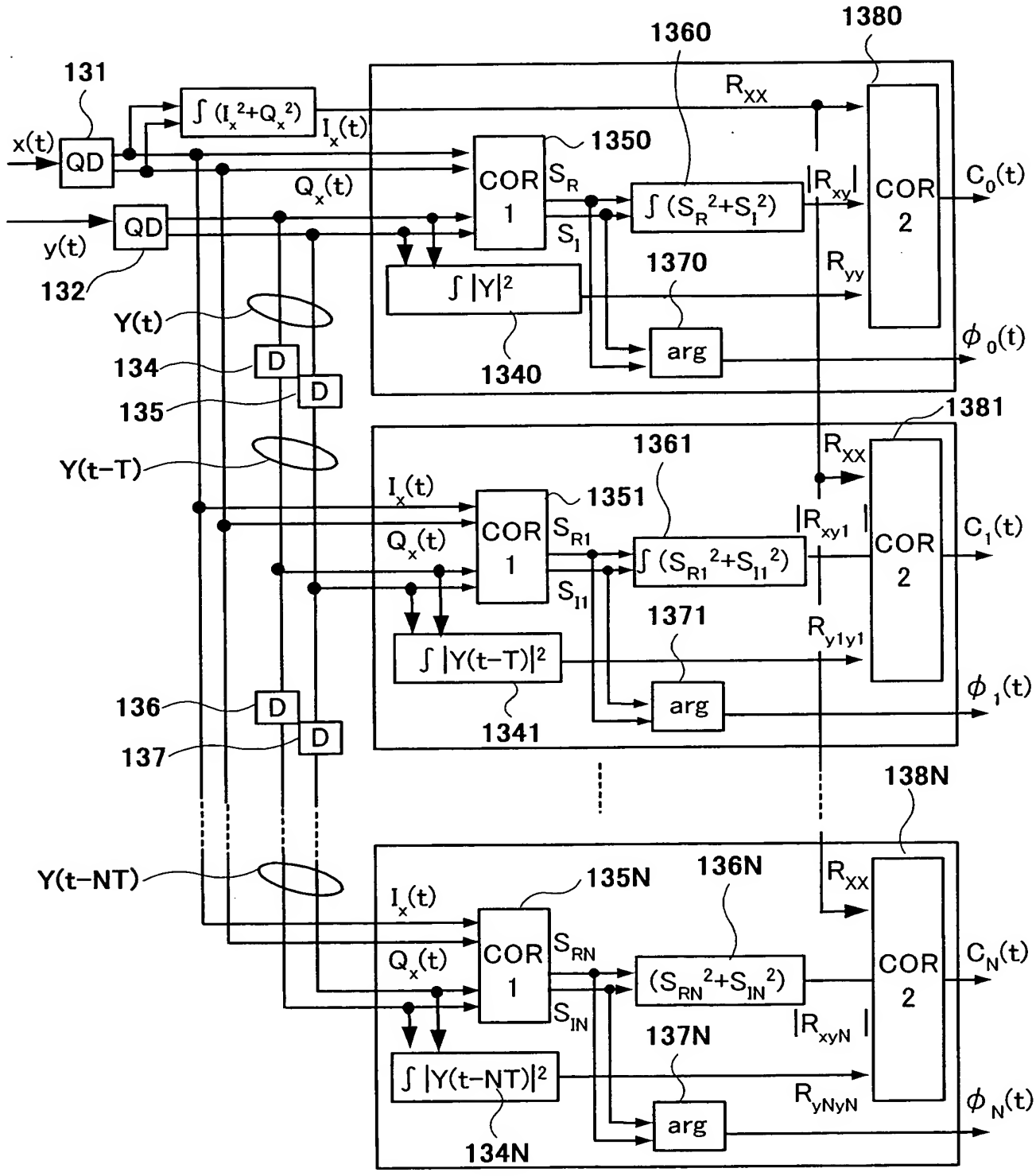

131
x(t)
QD
y(t)
QD
132
$\int (I_x^2+Q_x^2)$
$I_x(t)$
$Q_x(t)$
1360
1380
1350
COR 1
S_R
S_I
$\int (S_R^2+S_I^2)$
R_{XX}
$|R_{xy}|$
R_{yy}
COR 2
$C_0(t)$
1370
$\int |Y|^2$
1340
arg
$\phi_0(t)$
Y(t)
134
D
135
D
Y(t-T)
1381
1361
1351
S_{R1}
S_{I1}
$\int (S_{R1}^2+S_{I1}^2)$
$|R_{xy1}|$
$C_1(t)$
1371
$\int |Y(t-T)|^2$
1341
R_{y1y1}
$\phi_1(t)$
136
D
137
D
138N
Y(t-NT)
135N
136N
S_{RN}
S_{IN}
$(S_{RN}^2+S_{IN}^2)$
$|R_{xyN}|$
$C_N(t)$
137N
$\int |Y(t-NT)|^2$
134N
R_{yNyN}
$\phi_N(t)$

FIG. 12

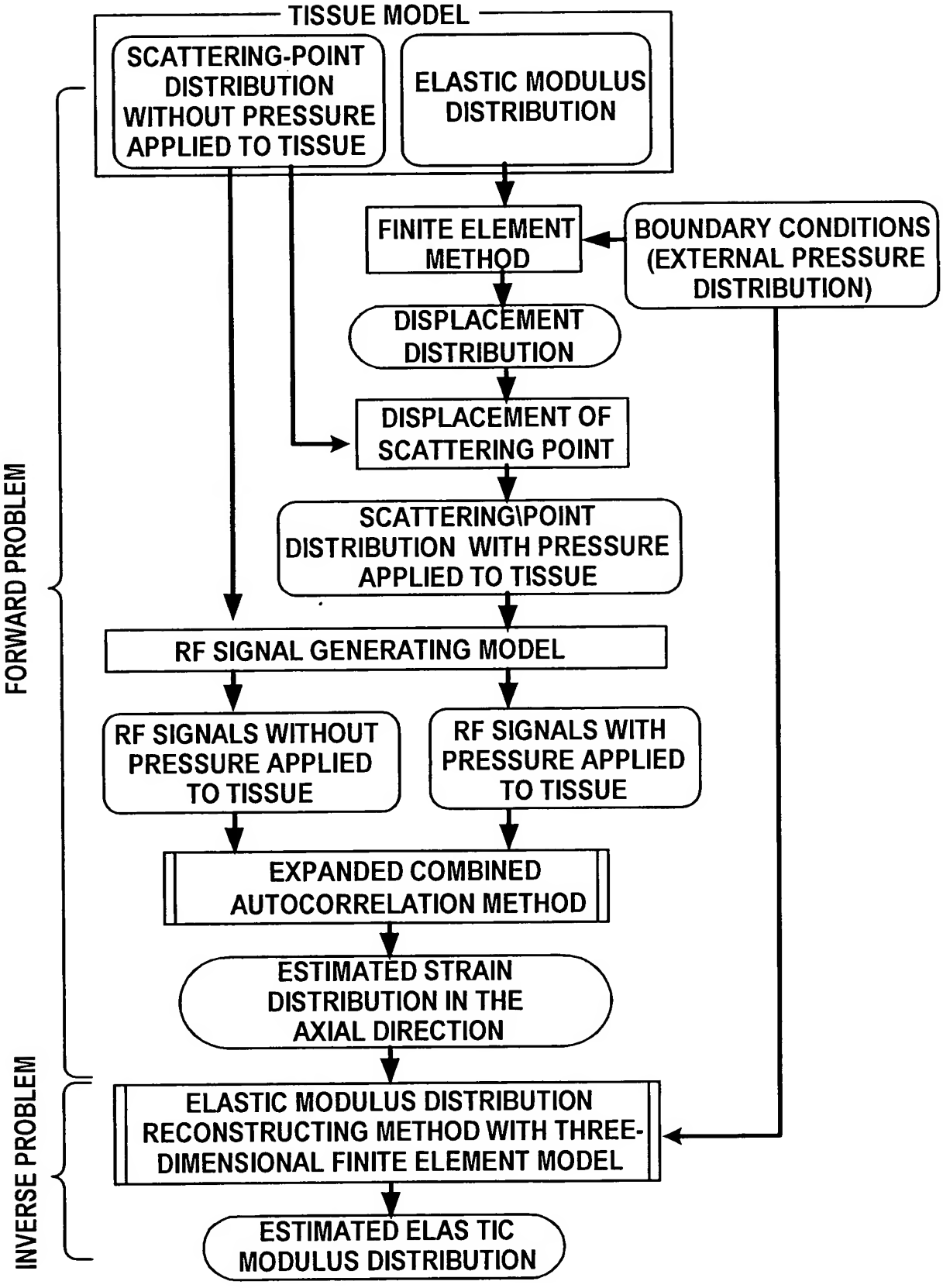

TISSUE MODEL
SCATTERING-POINT DISTRIBUTION WITHOUT PRESSURE APPLIED TO TISSUE
ELASTIC MODULUS DISTRIBUTION
FINITE ELEMENT METHOD
BOUNDARY CONDITIONS (EXTERNAL PRESSURE DISTRIBUTION)
DISPLACEMENT DISTRIBUTION
DISPLACEMENT OF SCATTERING POINT
SCATTERING\POINT DISTRIBUTION WITH PRESSURE APPLIED TO TISSUE
RF SIGNAL GENERATING MODEL
RF SIGNALS WITHOUT PRESSURE APPLIED TO TISSUE
RF SIGNALS WITH PRESSURE APPLIED TO TISSUE
EXPANDED COMBINED AUTOCORRELATION METHOD
ESTIMATED STRAIN DISTRIBUTION IN THE AXIAL DIRECTION
ELASTIC MODULUS DISTRIBUTION RECONSTRUCTING METHOD WITH THREE-DIMENSIONAL FINITE ELEMENT MODEL
ESTIMATED ELAS TIC MODULUS DISTRIBUTION
FORWARD PROBLEM
INVERSE PROBLEM

FIG. 13(A)

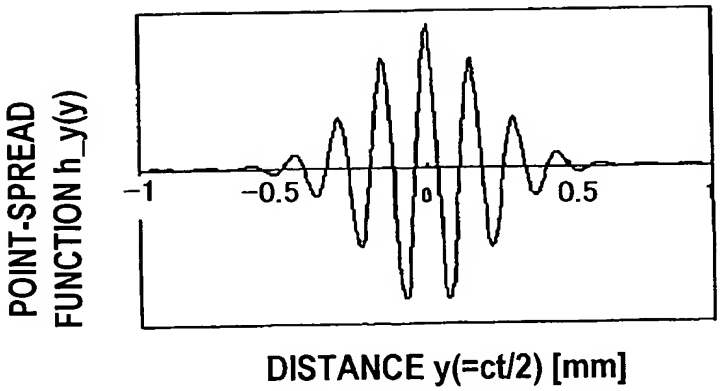


FIG. 13(B)

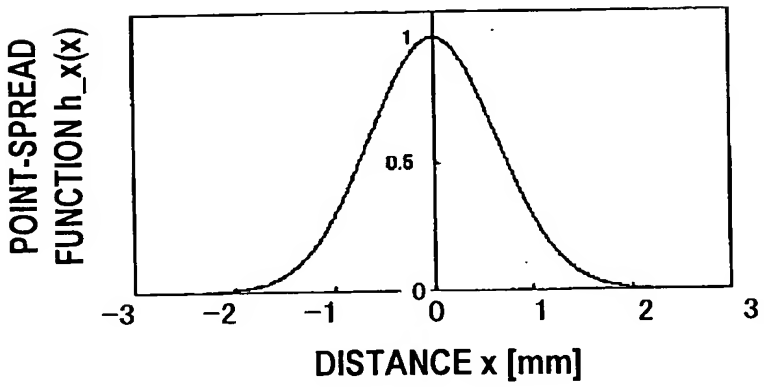


FIG. 13(C)

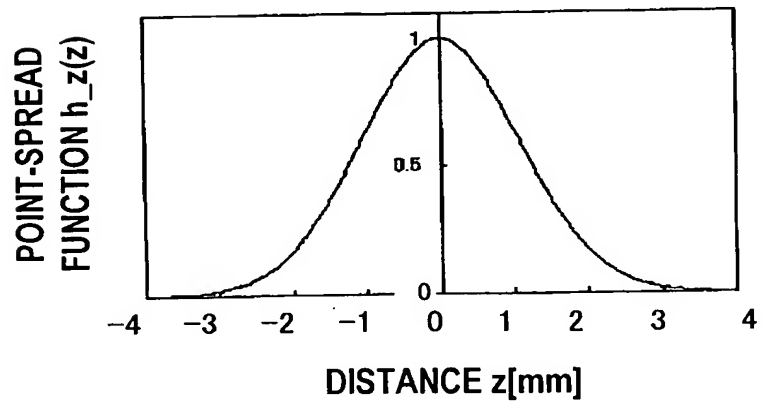


FIG. 14

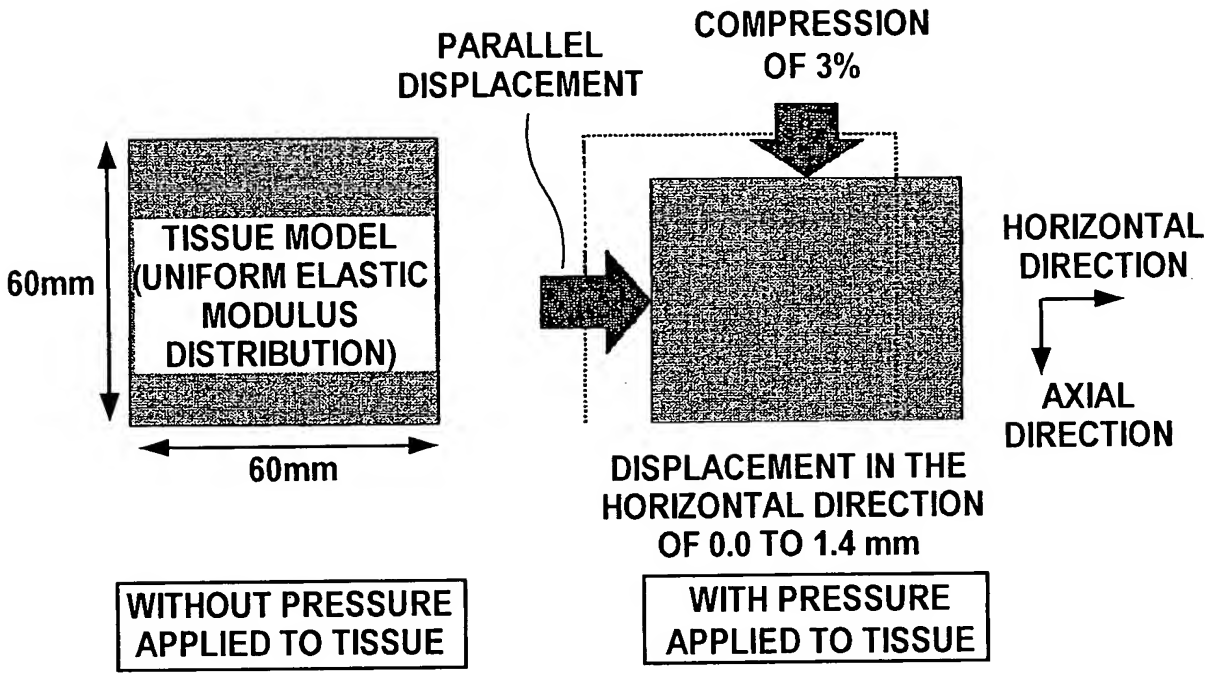

PARALLEL DISPLACEMENT
COMPRESSION OF 3%
60mm
TISSUE MODEL (UNIFORM ELASTIC MODULUS DISTRIBUTION)
60mm
HORIZONTAL DIRECTION
AXIAL DIRECTION
DISPLACEMENT IN THE HORIZONTAL DIRECTION OF 0.0 TO 1.4 mm
WITHOUT PRESSURE APPLIED TO TISSUE
WITH PRESSURE APPLIED TO TISSUE

FIG. 15

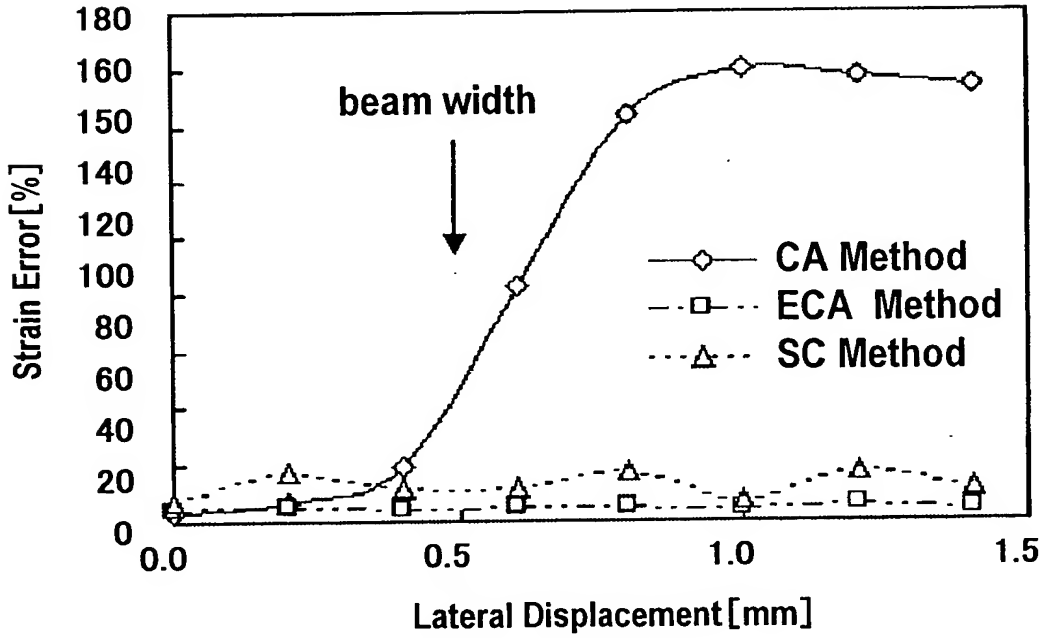

180
160
150
140
120
100
80
60
40
20
0
Strain Error[%]
beam width
CA Method
ECA Method
SC Method
0.0
0.5
1.0
1.5
Lateral Displacement[mm]

FIG. 16(A)

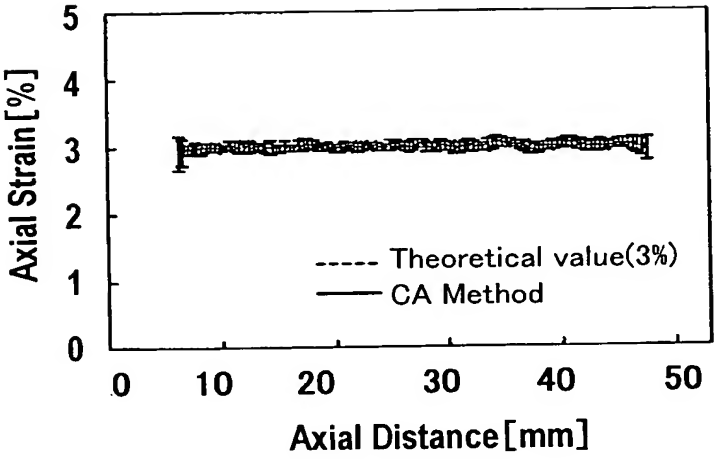


FIG. 16(B)

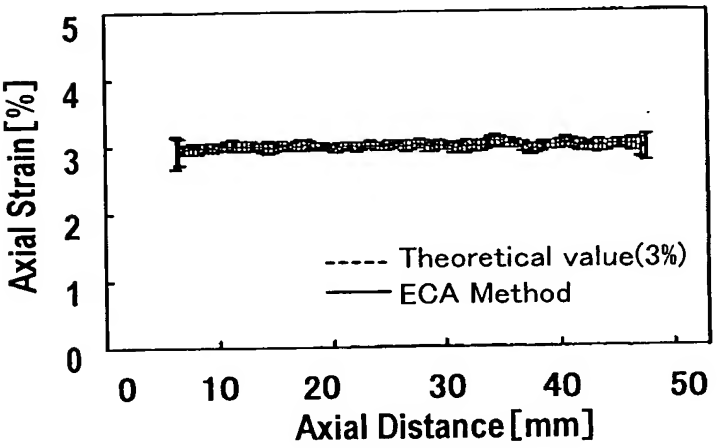


FIG. 16(C)

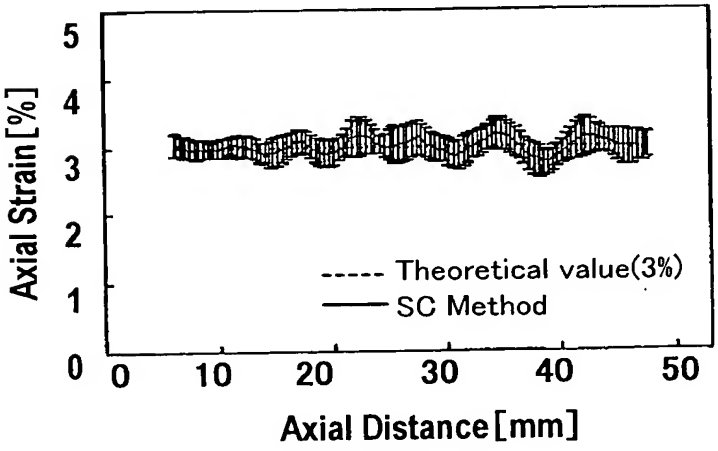


FIG. 17(A)

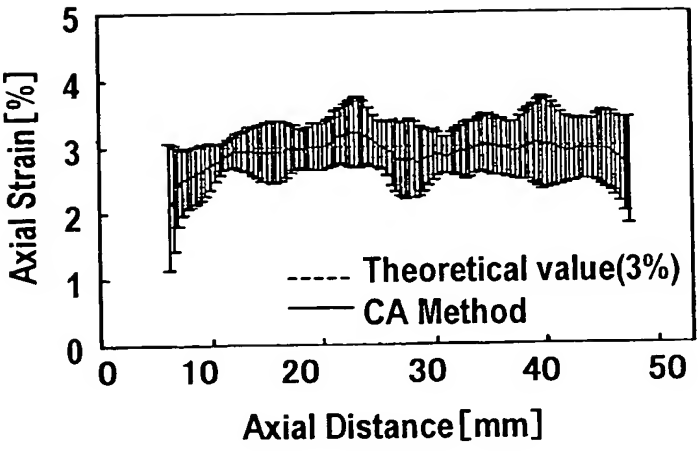


FIG. 17(B)

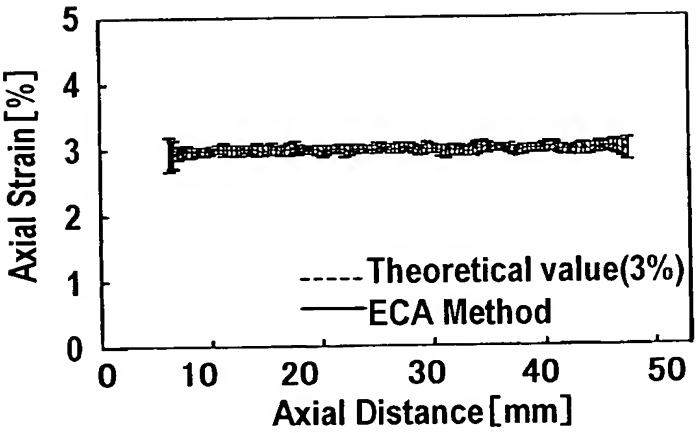


FIG. 17(C)

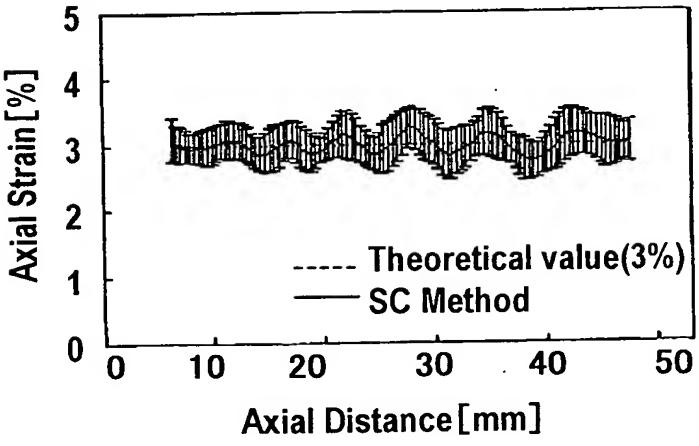


FIG. 18(A)

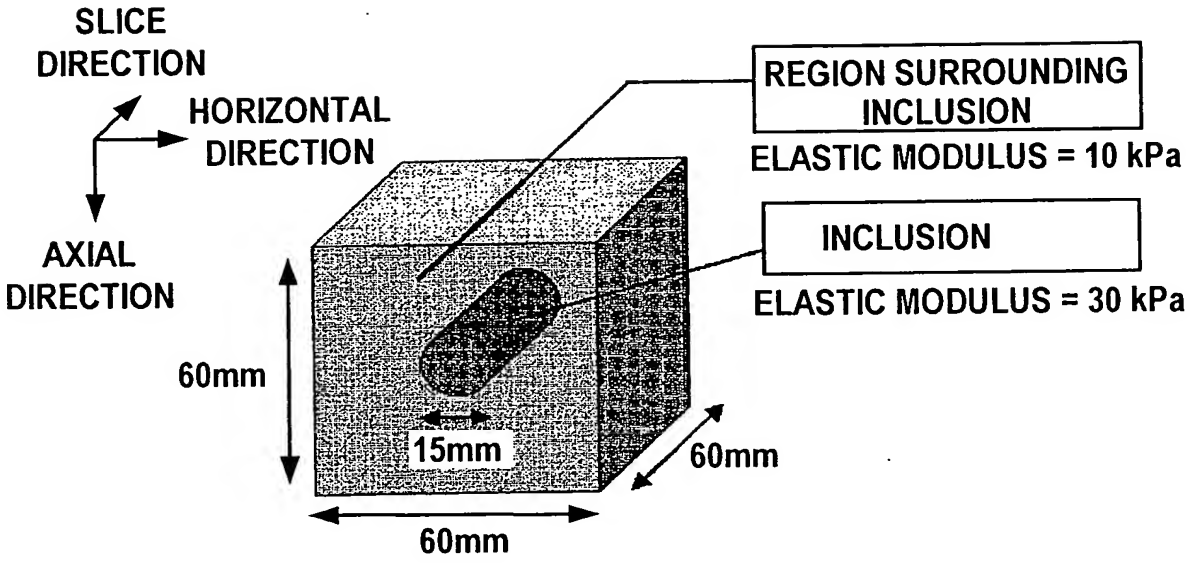
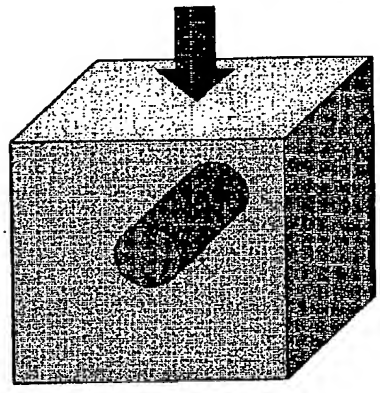


FIG. 18(B)

EXTERNAL PRESSURE OF 200 Pa IN THE AXIAL DIRECTION (UNIFORM PRESSURE APPLIED TO UPPERFACE OF MODEL)

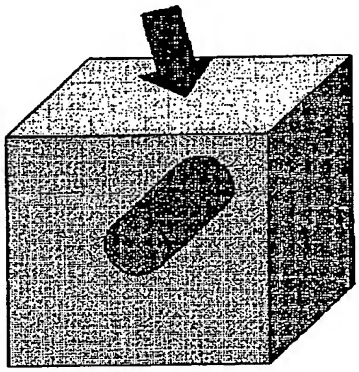


BOTTOM OF THE MODEL IS FIXED

COMPRESSION IN IN THE AXIAL DIRECTION

FIG. 18(C)

EXTERNAL PRESSURE OF 200 Pa IN THE AXIAL DIRECTION AND 30 Pa (UNIFORM PRESSURE APPLIED TO UPPERFACE OF MODEL)



BOTTOM OF THE MODEL IS FIXED

COMPRESSION IN IN A SLANT DIRECTION

FIG. 19(a)

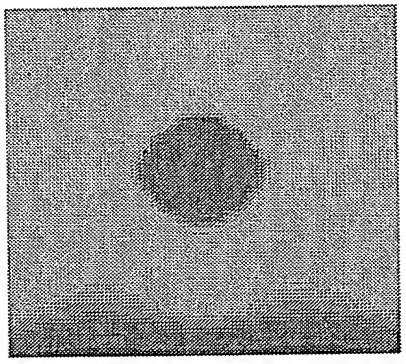


FIG. 19(b)

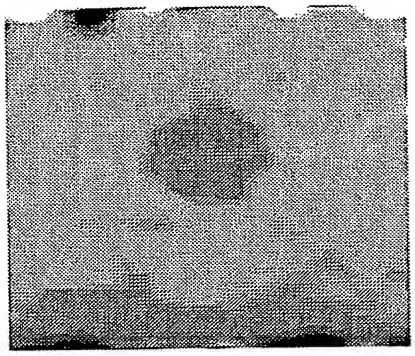


FIG. 19(c)

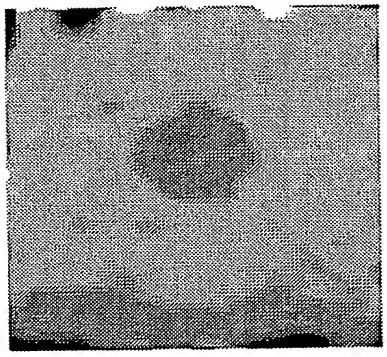


FIG. 19(d)

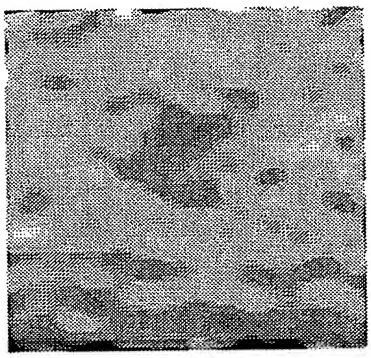


FIG. 20(a)

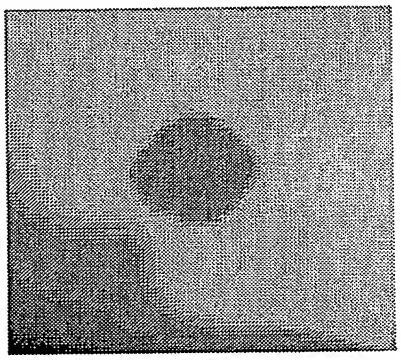


FIG. 20(b)

FIG. 20(c)

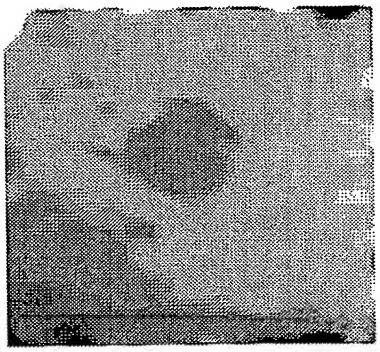


FIG. 20(d)

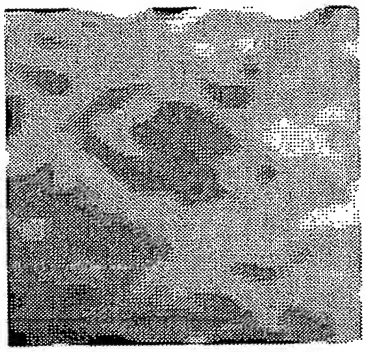


FIG. 21(a)

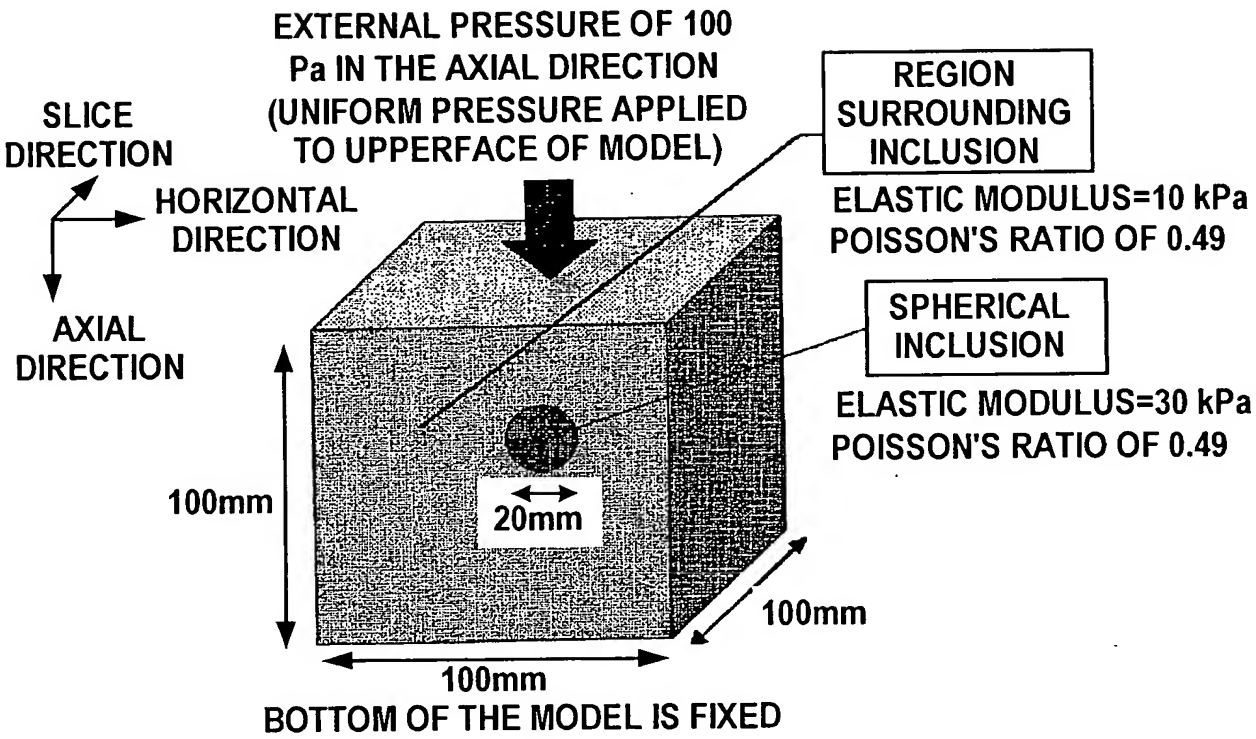


FIG. 21(b)

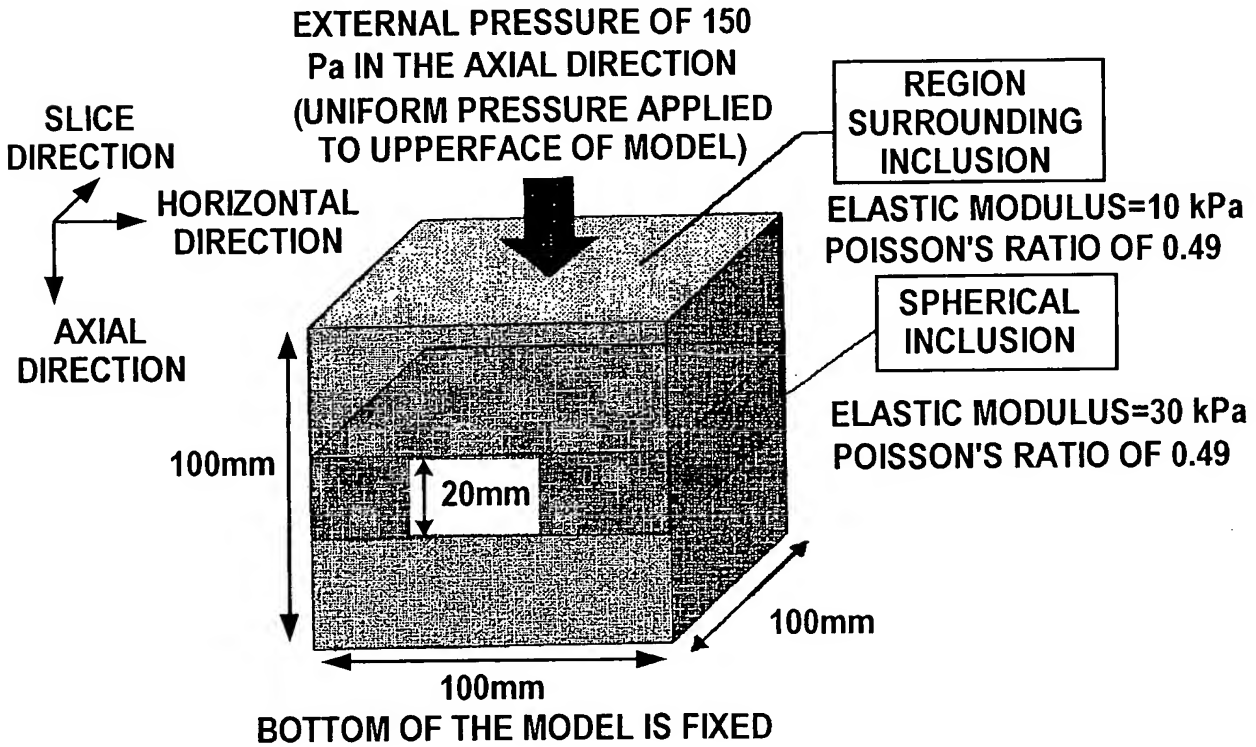


FIG. 22(a)

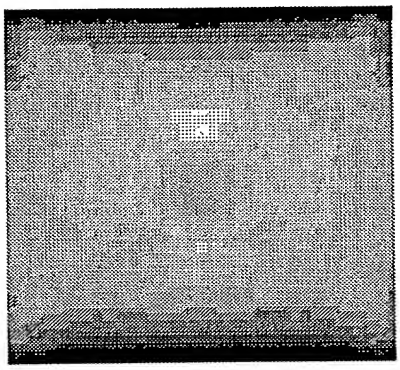


FIG. 22(b)

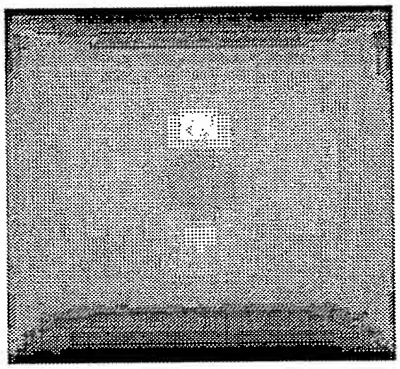


FIG. 22(c)

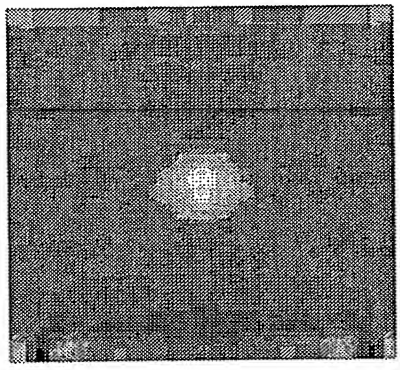


FIG. 22(d)

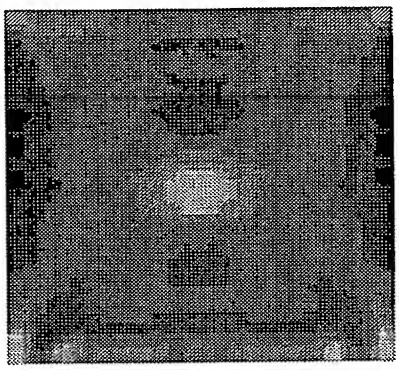


FIG. 23(a)

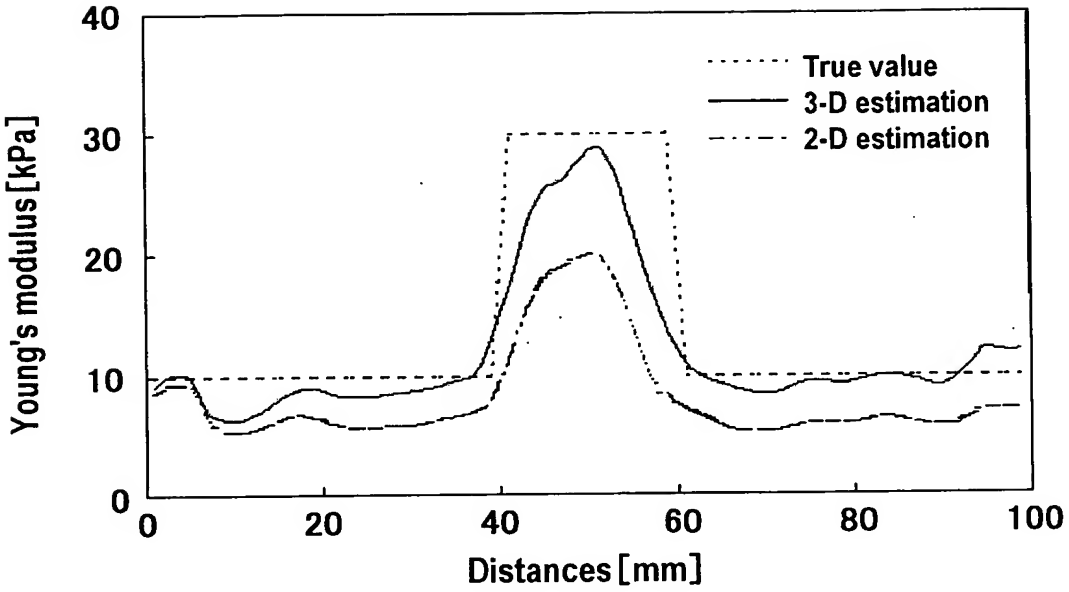


FIG. 23(b)

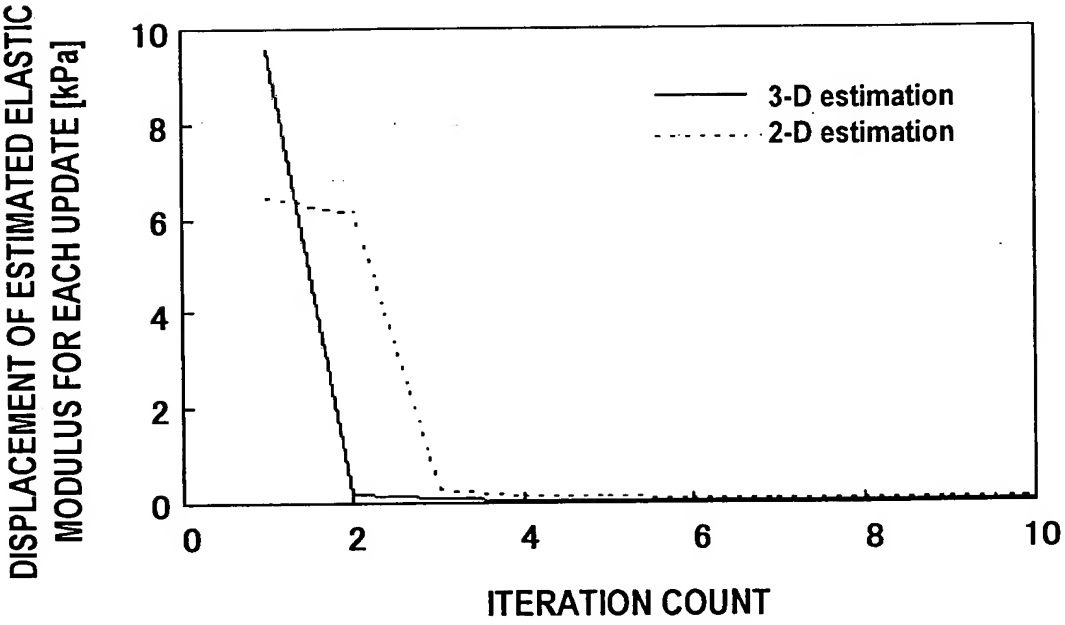


FIG. 24(a)

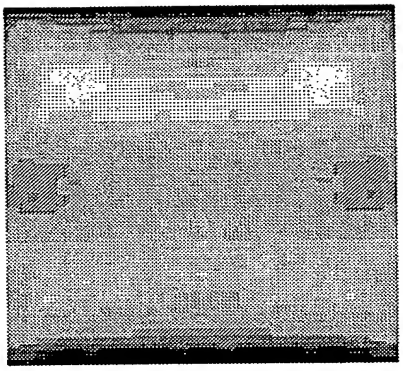


FIG. 24(b)

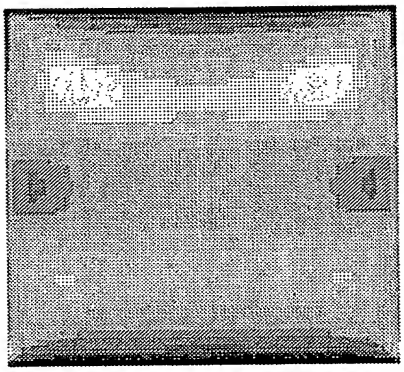


FIG. 24(c)

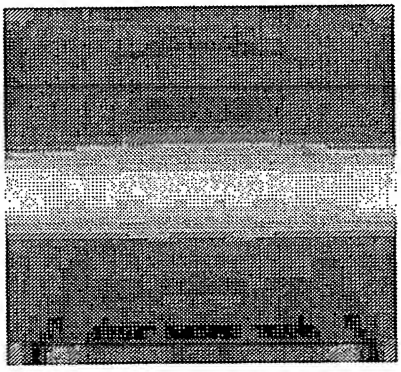


FIG. 24(d)

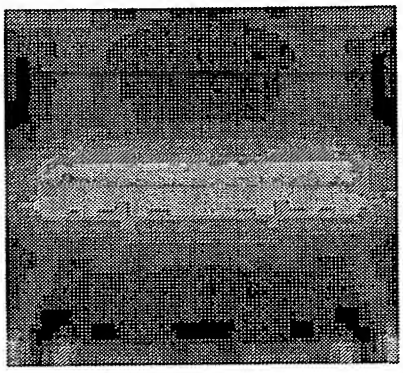


FIG. 25(a)

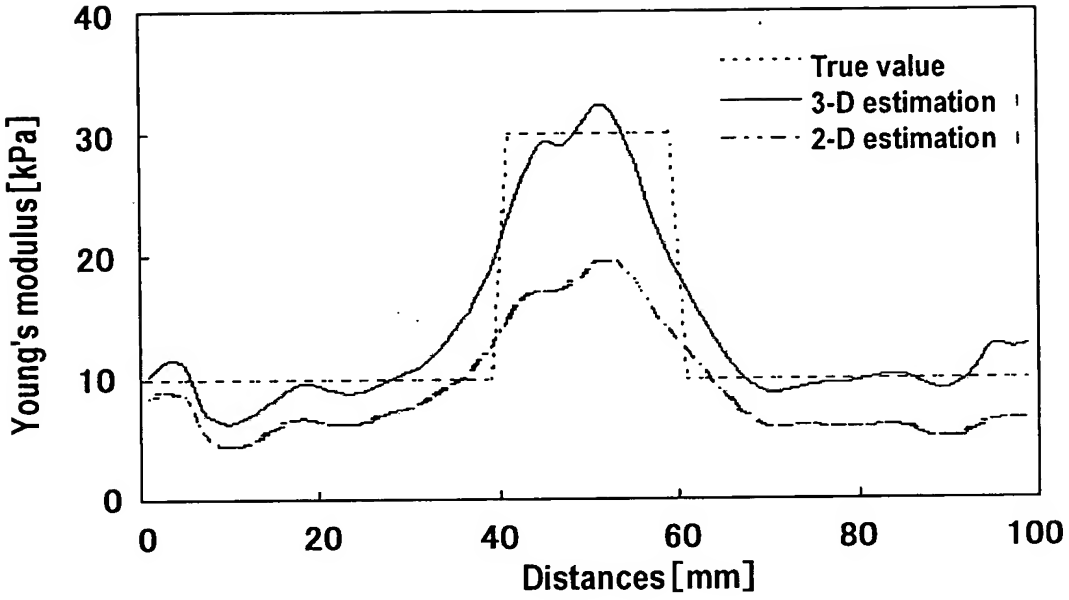


FIG. 25(b)

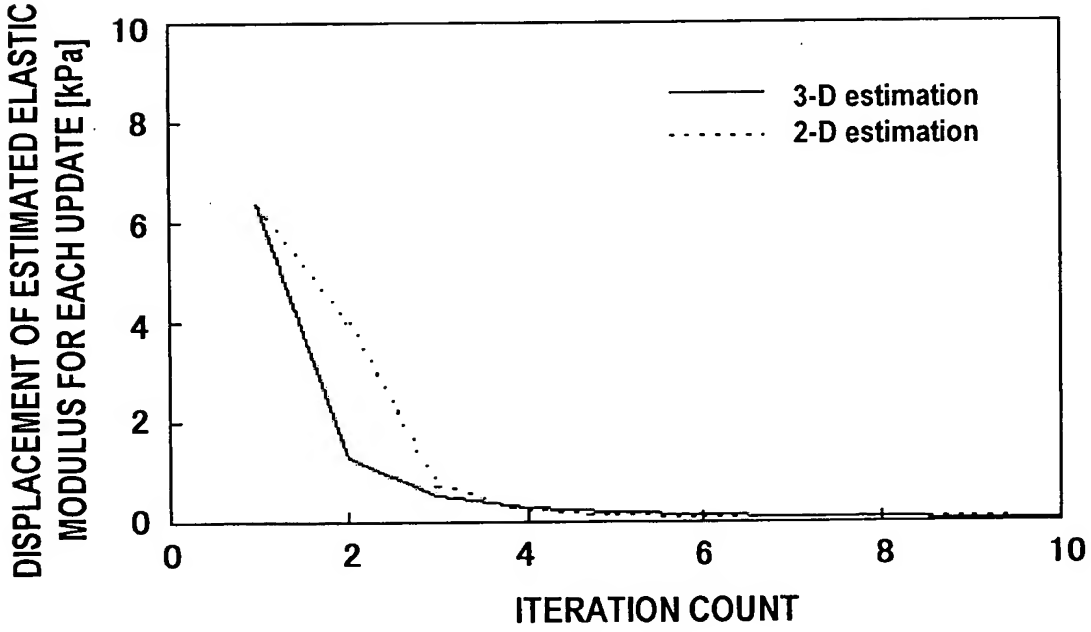


FIG. 26

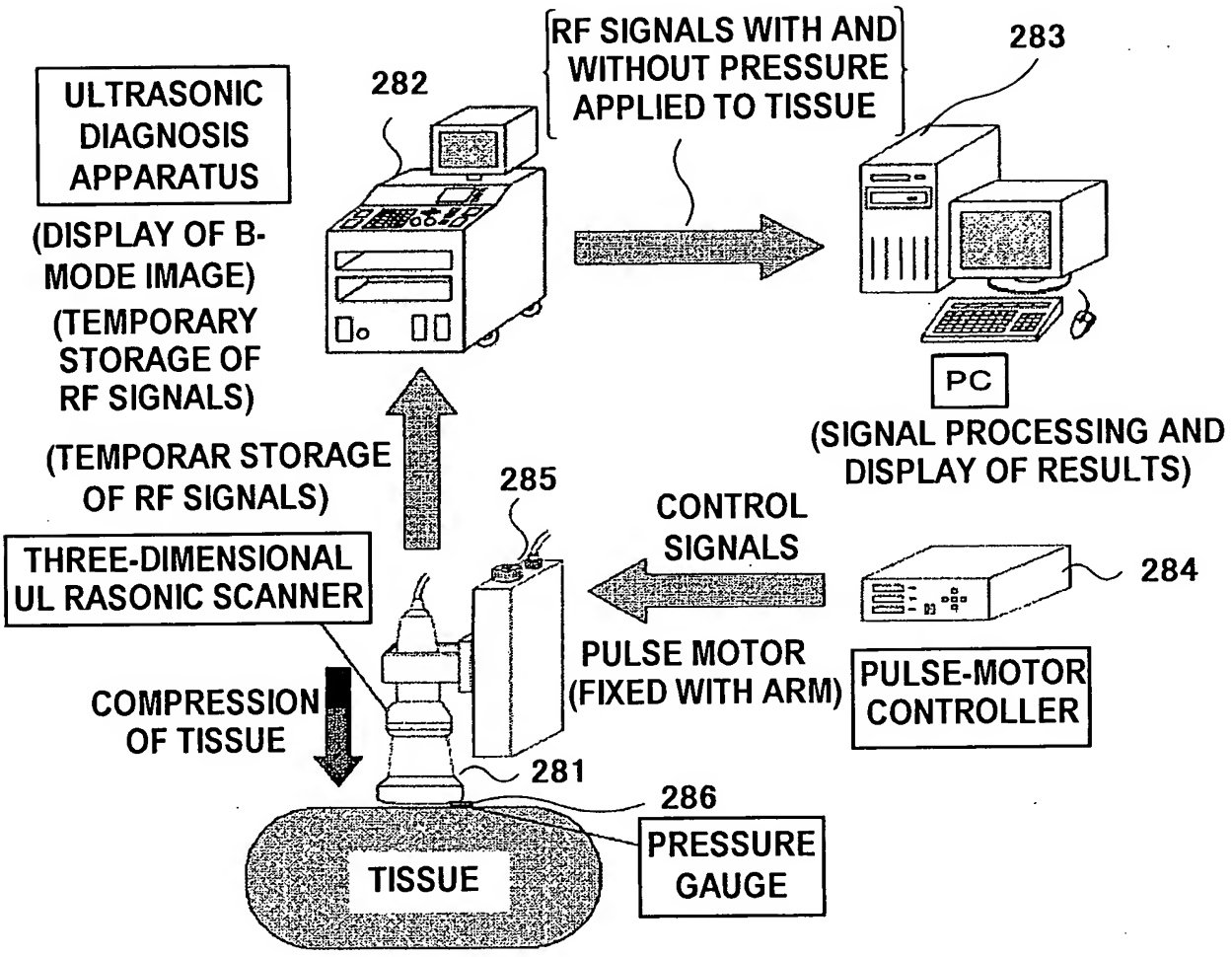
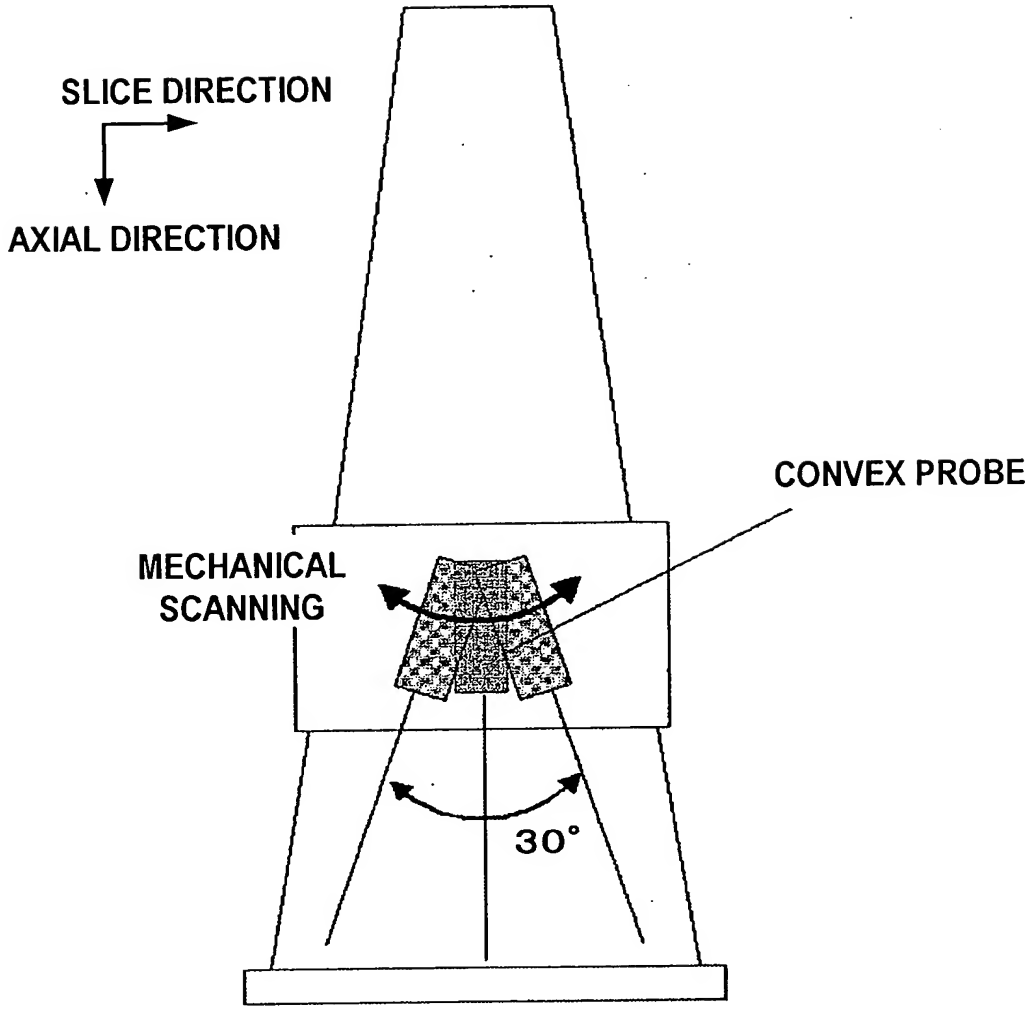

ULTRASONIC DIAGNOSIS APPARATUS
(DISPLAY OF B-MODE IMAGE)
(TEMPORARY STORAGE OF RF SIGNALS)
282
RF SIGNALS WITH AND WITHOUT PRESSURE APPLIED TO TISSUE
283
PC
(SIGNAL PROCESSING AND DISPLAY OF RESULTS)
(TEMPORAR STORAGE OF RF SIGNALS)
285
CONTROL SIGNALS
284
THREE-DIMENSIONAL UL RASONIC SCANNER
PULSE MOTOR (FIXED WITH ARM)
PULSE-MOTOR CONTROLLER
COMPRESSION OF TISSUE
281
286
PRESSURE GAUGE
TISSUE

FIG. 27


SLICE DIRECTION
AXIAL DIRECTION
CONVEX PROBE
MECHANICAL SCANNING
30°